

Wind Resource Assessment for TOKSOOK BAY, ALASKA Site # 0071

Date last modified: 10/4/2005
Compiled by: Mia Devine



Latitude: (NAD27)	60° 31' 38.9" N 60° 31.648
Longitude: (NAD27)	165° 6' 28.5" W -165° 6.475

Elevation:	65 ft
Tower Type:	30-meter NRG Tall Tower
Monitor Start:	6/16/2004
Monitor End:	08/31/2005

INTRODUCTION

On June 16, 2004, V3Energy and employees of the Alaska Village Electric Cooperative (AVEC) installed a 30-meter meteorological tower in the village of Toksook Bay. The purpose of this monitoring effort was to evaluate the feasibility of utilizing wind energy in the community. AVEC began installing three wind turbines in Toksook Bay in August of 2005. This report summarizes the wind resource data collected before the wind turbines were installed and the long-term energy production potential of the site.

SITE DESCRIPTION

Toksook Bay is located on Nelson Island in Kangirivik Bay, approximately 115 miles northwest of Bethel. The met tower and current wind farm site is located at the west end of town near the AVEC power plant. This location is at a slightly higher elevation than the town site. Figure 1 shows the location of the met tower relative to the surrounding terrain.

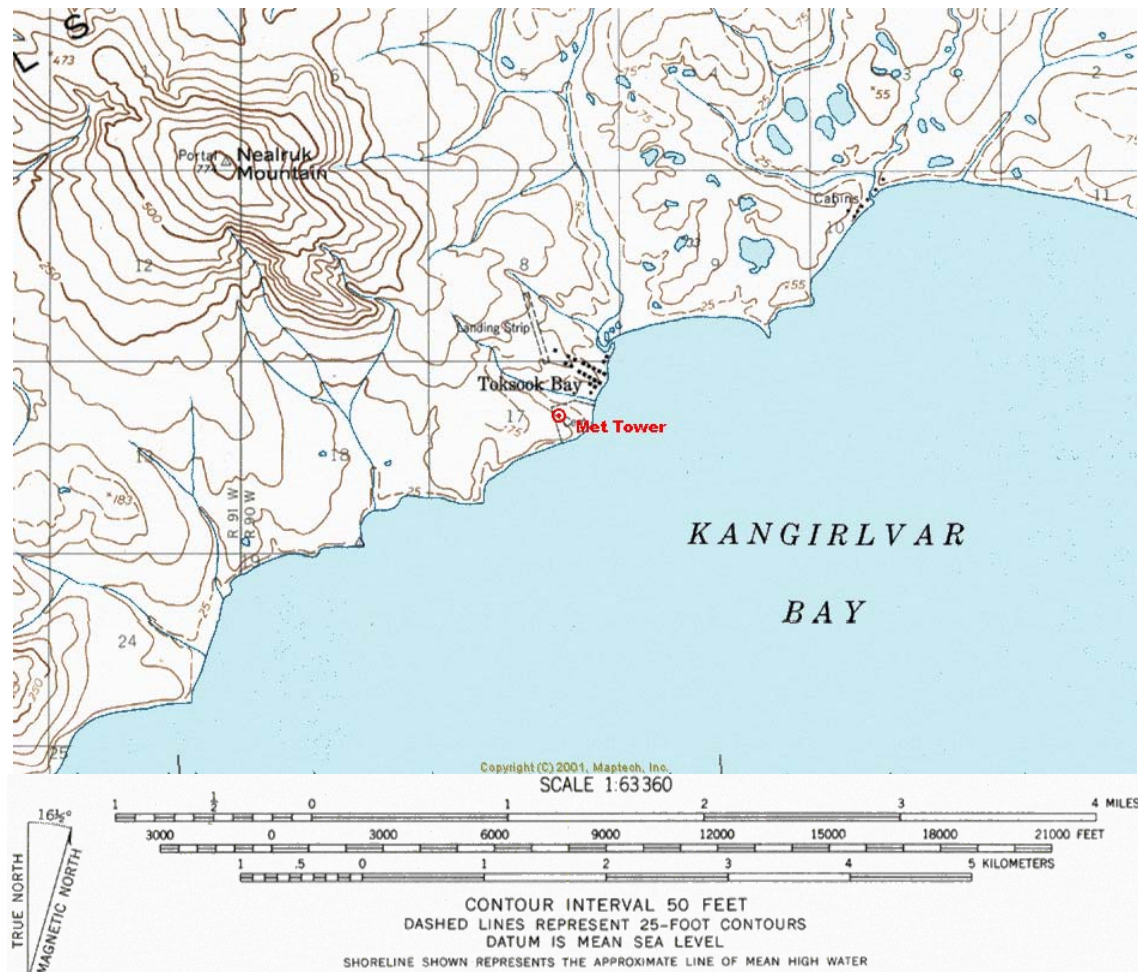
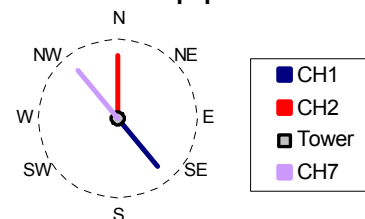


Figure 1. Topographic Map of Met Tower Site and Surrounding Area

Table 1 lists the types of sensors that were mounted on the met tower, the channel of the data logger that each sensor was wired into, and where each sensor was mounted on the tower.

Table 1. Summary of Sensors Installed on the Met Tower

Ch #	Sensor Type	Height	Offset	Boom Orientation
1	#40 Anemometer	30 m	NRG Standard	140° True
2	#40 Anemometer	20 m	NRG Standard	True North
7	#200P Wind Vane	30 m	140° True	320° True
9	#110S Temperature	5 m	0	-

Arial view of equipment on tower

The photos below illustrate the terrain surrounding the met tower site.



Photo by Mia Devine

View of met tower from power plant



Photo by Eric Marchegiani

Facing NW towards met tower site



Photo by Doug Vaught

Facing SE from met tower site



Photo by Mia Devine

View of sensor layout



Photo by Mia Devine

Facing East



Photo by Doug Vaught

Facing West/NW



Photo by Doug Vaught

Facing NE



Photo by Mia Devine

Facing west towards met tower site

DATA PROCESSING PROCEDURES AND DEFINITIONS

The following information summarizes the data processing procedures that were performed on the raw measured data in order to create an annual dataset of “typical” wind speeds, which could then be used to calculate potential power production from wind turbines. There are various methods and reasons for adjusting the raw data, so the purpose of these notes is to document what was done in this situation. The raw data set is available on the Alaska Energy Authority website (www.akenergyauthority.org) so one could perform their own data processing procedures.

Units – Since most wind turbine manufacturer data is provided in metric units, those units are used here.

1 meter/second = 2.24 mph = 1.95 knots

1 meter = 3.28 feet

1 °C = 5/9 (°F – 32)

Max/Min Test – All of the 10-minute data values were evaluated to ensure that none of them fell outside of the normal range for which the equipment is rated.

Tower Shadow – The tower itself can affect readings from the anemometer at times when the anemometer is located downwind of the tower. In this case, the 30-meter anemometer may record slightly lower values than the free stream velocity when the wind is coming from the NW.

Icing – Anomalies in the data can suggest when the sensors were not recording accurately due to icing events. Since wind vanes tend to freeze before the anemometers, icing events are typically identified whenever the 10-minute standard deviation of the wind vane is zero (the wind vane is not moving) and the temperature is at or below freezing. Some additional time before and after the icing event are filtered out to account for the slow build up and shedding of ice.

Filling Gaps – Whenever measured met tower data is available, it is used. Two different methods are used to fill in the remaining portion of the year. First, nearby airport data is used if available. A linear correlation equation is defined between the airport and met tower site, which is used to adjust the hourly airport data recorded at the time of the gap. If neither met tower nor airport data is available for a given timestep, the software program Windographer (www.mistaya.ca) is used. Windographer uses statistical methods based on patterns in the data surrounding the gap, and is good for filling short gaps in data.

Long-term Estimates – The year of data collected at the met tower site can be adjusted to account for inter-annual fluctuations in the wind resource. To do this, a nearby weather station with a consistent historical record of wind data and with a strong correlation to the met tower location is needed. If a suitable station is not available, there is a higher level of uncertainty in the wind speed that is measured being representative of a typical year.

Turbulence Intensity – Turbulence intensity is the most basic measure of the turbulence of the wind. Turbulence intensity is calculated at each 10-minute timestep by dividing the standard deviation of the wind speed during that timestep by the average wind speed over that timestep. It is calculated only when the mean wind speed is at least 4 m/s. Typically, a turbulence intensity of 0.10 or less is desired for minimal wear on wind turbine components.

Wind Shear – Typically, wind speeds increase with height above ground level. This vertical variation in wind speed is called wind shear and is influenced by surface roughness, surrounding terrain, and atmospheric stability. The met tower is equipped with anemometers at different heights so that the wind shear exponent, α , can be calculated according to the power law formula:

$$\left(\frac{H_1}{H_2}\right)^\alpha = \left(\frac{v_1}{v_2}\right) \text{ where } H_1 \text{ and } H_2 \text{ are the measurement heights and } v_1 \text{ and } v_2 \text{ are the measured wind speeds.}$$

Wind shear is calculated only with wind speed data above 4 m/s. Values can range from 0.05 to 0.25, with a typical value of 0.14.

Scaling to Hub Height – If the wind turbine hub height is different from the height at which the wind resource is measured, the wind resource can be adjusted using the power law formula described above and using the wind shear data calculated at the site.

Air Density Adjustment – The power that can be extracted from the wind is directly related to the density of the air. Air density, ρ , is a function of temperature and pressure and is calculated for each 10-minute timestep according to the following equation (units for air density are kg/m³):

$$\rho = \frac{P}{R \times T}, \text{ where } P \text{ is pressure (kPa), } R \text{ is the gas constant for air (287.1 J/kgK), and } T \text{ is temperature in Kelvin.}$$

Since air pressure is not measured at the met tower site, the site elevation is used to calculate an annual average air pressure value according to the following equation:

$$P = 1.225 - (1.194 \times 10^{-4}) \times \text{elevation}$$

Since wind turbine power curves are based on a standard air density of 1.225 kg/m³, the wind speeds measured at the met tower site are adjusted to create standard wind speed values that can be compared to the standard power curves. The adjustment is made according to the following formula:

$$V_{s \text{ tan dard}} = V_{measured} \times \left(\frac{\rho_{measured}}{\rho_{s \text{ tan dard}}} \right)^{\frac{1}{3}}$$

Since the temperature sensor in Toksook Bay was not working, the wind speed measurements were not adjusted for air density.

Wind Power Density – Wind power density provides a more accurate representation of a site's wind energy potential than the annual average wind speed because it includes how wind speeds are distributed around the average as well as the local air density. The units of wind power density are watts per square meter and represent the power produced per square meter of area that the blades sweep as they rotate around the rotor.

Wind Power Class – A seven level classification system based on wind power density is used to simplify the comparison of potential wind sites. Areas of Class 4 and higher are considered suitable for utility-scale wind power development.

Weibull Distribution – The Weibull distribution is commonly used to approximate the wind speed frequency distribution in many areas when measured data is not available. In this case, the Weibull distribution is used to compare with our measured data. The Weibull is defined as follows:

$$P(v) = \frac{k}{c} \left(\frac{v}{c} \right)^{k-1} \exp \left(- \left(\frac{v}{c} \right)^k \right)$$

Where $P(v)$ is the probability of wind speed v occurring, c is the scale factor which is related to the average wind speed, and k is the shape factor which describes the distribution of the wind speeds. Typical k values range from 1.5 to 3.0, with lower k values resulting in higher average wind power densities.

DATA COLLECTION PROBLEMS

Originally, the offset for the temperature sensor was programmed into the data logger at a value of 0 instead of the standard -123.501 so that the readings would match those of the data logger's internal temperature sensor. The temperature readings seemed to be accurate until 9/9/2004, when the temperature reading began to drift up to a value of over 150°F on 9/12/2004. The signal conditioning module (SCM) for the temperature sensor was removed and re-inserted at 16:30 on 2/22/2005, which seemed to correct the problem. For the data between 9/12/2004 and 2/22/2005, the standard offset of -123.501 was programmed into the data management software to adjust the invalid readings from the logger. Temperature data between 9/9/2004 and 9/12/2004 was discarded. To ensure that the revised temperature dataset is valid, the hourly average values were compared to those from the Mekoryuk airport weather station, located about 40 miles to the West. The temperature data sets matched closely, with a correlation coefficient of 0.94 (value of 1 is perfect).

On 5/22/05 the data logger failed and was replaced on 6/9/05. This resulted in a gap in the entire dataset.

LONG-TERM REFERENCE STATION

Wind data from the Mekoryuk Airport weather station (shown in Figure 2), located about 40 miles west of the met tower site, serves as a long-term reference for the wind resource in the area. This data is measured at a height of 10 meters above ground level and at an elevation of 15 meters.

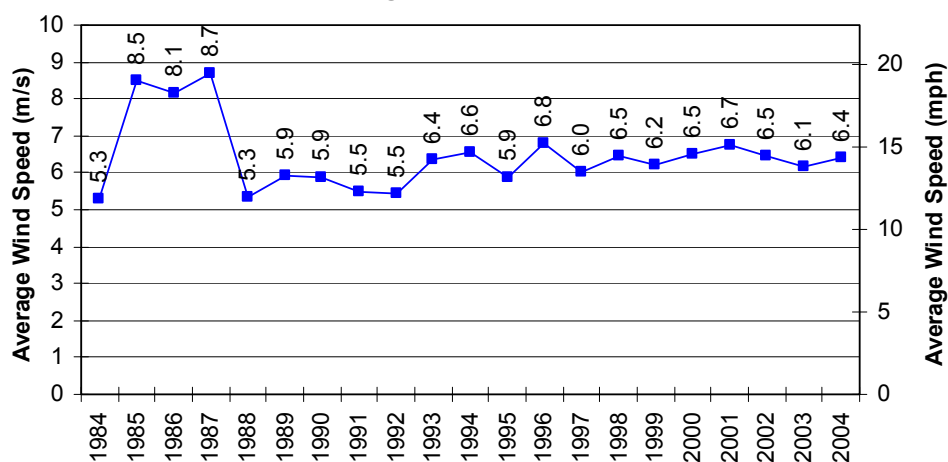


Figure 2. ASOS Equipment in Mekoryuk

Over 20 years of wind speed measurements are summarized in Table 2 and Figure 3. The average wind speed over the 20-year period is 6.4 m/s. The cause of the unusually high wind speeds in 1985-1987 is unknown. Excluding those years, the annual wind speed rarely deviates more than 10% above or below the average.

Table 2. Average Wind Speeds at 10-meter Height at Mekoryuk Airport

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG	% of 20-Yr Average
1984	7.0	6.1	5.5	5.4	3.4	3.3	4.5	5.8	4.0	6.2	4.8	7.2	5.3	82%
1985	6.4	6.7	6.9	8.3	9.2	7.1	7.1	7.8	9.9	12.3	11.5	8.7	8.5	132%
1986	9.6	9.0	8.7	7.5	7.4	8.6	6.3	7.2	6.4	7.6	9.8	9.8	8.1	127%
1987	9.8	9.6	7.5	8.9	7.6	7.4	7.3	7.3	9.9	9.5	9.8	9.4	8.7	135%
1988	8.6	7.5	6.1	6.5	4.8	4.0	3.1	3.5	4.3	4.4	5.3	5.7	5.3	83%
1989	5.7	7.0	6.0	6.8	6.4	4.7	3.8	4.2	6.1	6.9	7.2	6.2	5.9	92%
1990	6.3	5.9	5.3	5.7	6.3	5.0	4.3	6.1	6.6	5.6	6.3	7.4	5.9	91%
1991	6.4	6.0	6.3	3.5	4.2	5.6	5.4	3.9	5.4	7.4	5.3	6.4	5.5	85%
1992	4.1	5.1	3.5	5.2	5.7	4.7	3.9	6.1	6.7	7.4	6.6	6.6	5.5	85%
1993	9.2	7.8	5.9	5.3	5.9	5.3	4.6	5.0	7.1	6.4	7.3	6.7	6.4	99%
1994	6.3	7.0	7.3	5.6	4.3	5.1	5.1	7.4	6.2	6.8	9.1	8.3	6.6	102%
1995	6.7	7.0	5.4	6.4	4.6	5.3	4.3	5.3	6.0	7.2	5.5	6.8	5.9	91%
1996	7.2	9.2	6.4	6.8	5.6	6.2	5.0	6.7	7.2	6.7	8.3	6.2	6.8	106%
1997	6.8	7.8	5.6	4.3	6.3	4.3	4.5	5.9	5.9	6.5	7.7	6.5	6.0	93%
1998	6.9	5.2	7.4	8.3	6.7	5.0	3.7	6.8	6.3	6.5	7.3	7.4	6.5	100%
1999	7.1	7.8	6.1	7.7	4.7	4.7	3.8	5.6	6.0	6.5	8.2	6.6	6.2	97%
2000	7.6	8.8	6.9	5.5	4.5	4.3	4.5	6.7	6.2	5.9	8.4	8.7	6.5	101%
2001	7.6	9.4	7.5	6.9	5.5	5.1	5.5	6.0	5.9	7.1	7.7	6.7	6.7	105%
2002	8.6	7.6	6.9	7.6	6.6	4.7	5.0	5.5	6.4	6.4	6.3	6.1	6.5	101%
2003	5.8	5.9	7.6	6.8	4.9	5.3	5.5	4.9	5.4	7.8	7.3	6.5	6.1	95%
2004	6.8	7.6	6.7	6.3	6.0	4.8	4.3	5.1	5.9	7.4	7.7	8.4	6.4	100%
AVG	7.2	7.3	6.5	6.4	5.7	5.3	4.8	5.8	6.4	7.1	7.5	7.3	6.4	100%

**Figure 3. Annual Average Wind Speeds at 10-m Height at Mekoryuk Airport Weather Station**

Hourly wind speed measurements from the Mekoryuk Airport weather station that are concurrent with recordings from the Toksook Bay met tower site were purchased from the National Climatic Data Center. Data between these sites was compared and a correlation coefficient of 0.73 was calculated (a value of 1 is perfect). A bulk regression equation of the year of concurrent data was used to calculate a long-term wind speed dataset at the met tower site based on the long-term 2001-2005 data from the Mekoryuk airport site.

WIND DATA RESULTS FOR MET TOWER SITE

Table 3 summarizes the amount of data that was successfully retrieved from the 30-meter level anemometer at the met tower site. The month with the lowest data recovery rate is May, due to data logger failure. There is also significant data loss due to icing of the sensors in the winter months.

Table 3. Data Recovery Rates for Met Tower Data

Month	30 m
January	77%
February	71%
March	93%
April	95%
May	67%
June	82%
July	100%
August	100%
September	100%
October	96%
November	85%
December	91%
Annual Avg	88%

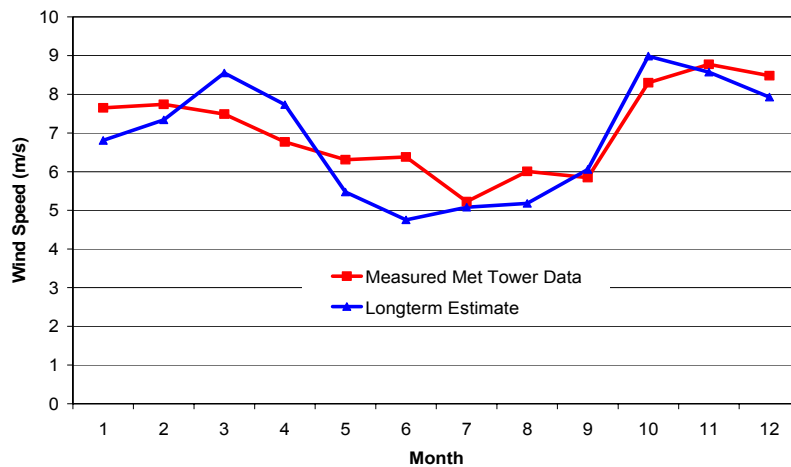
Table 4 and Table 5 summarize the wind resource data measured at the met tower site as well as the estimated long-term data for this site. Figure 4 and Figure 5 show this same data graphically. As shown, the highest wind month is November and the lowest wind month is July. Also, the diurnal variation is more pronounced during the summer months than the winter months, with winds typically lowest in the morning and increasing in the afternoon.

Table 4. Measured Wind Speeds at 30-m Height at Met Tower Location, June 2004 - Aug 2005 (m/s)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0	8.1	8.2	7.8	7.3	6.2	6.1	5.1	6.4	5.3	8.5	10.0	8.8	7.3
1	7.8	8.6	7.7	7.0	6.1	5.7	4.8	6.3	5.5	8.4	9.7	8.6	7.2
2	7.8	8.9	8.0	6.7	6.5	5.3	4.7	6.2	5.6	8.2	9.3	8.6	7.2
3	8.0	9.1	8.0	6.6	6.5	5.3	4.5	6.1	5.4	8.0	9.4	8.4	7.1
4	8.2	9.2	7.8	6.8	6.7	5.2	4.4	6.1	5.6	7.9	9.3	8.4	7.1
5	8.0	8.8	8.1	6.7	6.6	5.1	4.3	6.2	5.4	7.8	9.1	8.6	7.1
6	7.9	8.7	8.2	6.4	6.0	5.4	4.4	6.1	5.3	8.0	8.8	9.0	7.0
7	7.9	9.0	7.7	6.4	5.5	5.2	4.4	6.1	5.2	8.4	8.6	9.0	6.9
8	7.7	9.5	8.0	6.4	5.4	5.4	4.7	6.4	5.2	8.1	8.8	9.3	7.1
9	7.7	9.0	7.6	6.7	5.7	5.9	4.9	6.9	5.4	8.3	9.2	9.2	7.2
10	7.6	8.8	6.8	6.7	6.4	6.1	5.2	7.1	6.1	7.9	9.2	9.1	7.2
11	7.6	9.0	7.2	7.1	6.0	6.4	5.3	7.3	6.2	8.1	9.3	8.8	7.4
12	7.2	9.0	7.2	7.1	5.6	6.7	5.6	7.4	6.8	8.2	9.4	8.9	7.4
13	6.9	8.1	7.7	7.2	5.6	6.9	5.8	7.4	6.7	8.6	9.1	8.8	7.4
14	7.0	7.8	7.5	7.3	6.0	7.1	5.9	7.7	6.6	8.5	8.9	8.2	7.4
15	7.5	7.5	7.5	6.9	6.4	7.3	6.1	7.6	6.6	8.8	8.8	8.4	7.4
16	7.7	7.6	7.7	7.4	6.6	7.7	6.0	7.5	6.8	8.8	8.7	8.6	7.6
17	7.8	7.6	7.5	7.6	6.8	7.5	6.0	7.5	6.5	9.0	8.6	8.9	7.6
18	9.1	7.6	7.9	7.1	7.0	7.5	6.3	7.4	6.0	8.9	9.3	9.1	7.8
19	8.6	7.7	7.8	6.9	7.3	7.4	6.5	7.1	5.7	8.7	10.0	9.4	7.8
20	8.8	8.0	7.8	7.3	6.8	7.4	6.1	6.8	5.7	8.6	9.7	9.6	7.7
21	8.2	7.9	8.0	6.8	6.1	7.2	5.5	6.7	5.5	8.7	9.9	9.7	7.5
22	8.6	7.9	7.7	7.2	6.4	7.3	5.3	6.6	5.5	8.7	9.5	9.4	7.5
23	9.1	7.4	7.8	7.6	6.0	6.9	5.1	6.6	5.2	8.6	9.7	9.2	7.4
Avg	8.0	8.4	7.7	7.0	6.3	6.4	5.3	6.8	5.8	8.4	9.3	8.9	7.3

Table 5. Estimated Long-term Wind Speeds at 30-m Height at Met Tower Location (m/s)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0	6.5	6.6	8.9	7.4	4.3	2.6	3.9	4.3	5.6	8.5	8.6	7.1	6.2
1	6.4	6.7	8.7	7.3	4.0	2.9	4.0	4.3	5.3	8.4	8.4	7.1	6.1
2	6.4	6.9	8.5	6.9	3.6	2.7	4.0	4.1	5.4	8.5	8.4	7.2	6.1
3	6.4	7.3	8.5	6.8	3.9	2.7	3.6	3.8	5.2	8.6	8.0	7.7	6.0
4	7.3	7.2	8.6	7.1	4.1	2.6	3.8	4.0	5.2	8.5	8.1	8.0	6.2
5	7.4	7.3	8.8	7.0	3.9	2.4	3.8	3.7	5.2	8.8	8.3	8.0	6.2
6	7.3	7.5	8.6	7.1	4.0	2.7	3.7	3.7	5.2	8.7	9.2	8.2	6.3
7	7.6	7.5	8.6	7.5	4.2	3.3	3.8	3.9	5.5	9.0	8.2	8.4	6.5
8	7.4	7.3	8.7	7.6	4.6	4.3	4.4	4.0	5.6	8.9	8.2	8.1	6.6
9	7.3	7.1	8.3	7.3	5.3	5.0	5.0	4.7	5.8	8.7	8.2	7.9	6.7
10	7.6	7.5	8.1	7.9	5.7	5.6	5.5	5.4	6.3	8.9	8.5	8.3	7.1
11	7.1	7.6	8.3	8.3	6.4	6.2	6.2	5.7	6.5	9.1	8.3	8.3	7.3
12	6.9	7.8	7.9	8.6	6.9	6.5	6.2	6.1	6.7	9.5	8.6	8.0	7.5
13	6.4	7.5	8.1	8.5	7.3	7.1	6.3	6.5	6.8	9.7	9.0	8.2	7.6
14	6.8	7.7	8.2	8.8	7.2	7.2	6.7	6.8	7.1	9.5	8.7	8.0	7.7
15	6.5	7.9	8.2	8.9	7.0	7.5	6.7	7.0	7.2	9.5	8.8	8.2	7.8
16	6.7	7.7	8.8	8.6	7.1	7.3	6.7	6.7	6.9	9.7	8.9	8.3	7.8
17	6.9	8.2	8.8	8.5	7.2	6.8	6.5	6.8	6.9	9.6	8.8	8.3	7.8
18	6.9	7.6	9.0	8.3	7.0	6.4	6.3	6.7	6.7	9.0	8.7	8.0	7.6
19	6.5	7.0	8.8	7.5	6.7	5.9	6.0	6.0	6.5	9.2	8.7	8.2	7.2
20	6.4	7.4	8.9	7.6	6.3	5.4	5.5	5.6	5.9	9.1	8.7	8.1	7.1
21	6.4	6.9	8.3	7.5	5.5	4.6	5.0	5.0	5.8	9.0	8.7	7.6	6.7
22	6.1	7.3	8.6	7.4	4.8	3.4	4.4	4.7	5.9	8.7	8.8	7.3	6.5
23	6.2	6.7	9.0	7.2	4.4	2.9	4.0	4.5	6.2	8.2	8.9	7.7	6.3
Avg	6.8	7.3	8.5	7.7	5.5	4.8	5.1	5.2	6.1	9.0	8.6	7.9	6.9



Month	June 04 - Aug 05		Long-term Estimate	
	m/s	mph	m/s	mph
Jan	8.0	17.8	6.8	15.2
Feb	8.4	18.7	7.3	16.4
Mar	7.7	17.3	8.5	19.1
Apr	7.0	15.6	7.7	17.3
May	6.3	14.0	5.5	12.2
Jun	6.4	14.4	4.8	10.6
Jul	5.3	11.9	5.1	11.4
Aug	6.8	15.2	5.2	11.6
Sep	5.8	13.0	6.1	13.5
Oct	8.4	18.8	9.0	20.1
Nov	9.3	20.7	8.6	19.2
Dec	8.9	19.9	7.9	17.7
Avg	7.3	16.4	6.9	15.4

Figure 4. Monthly Average Wind Speeds at Met Tower Site (30m Height)

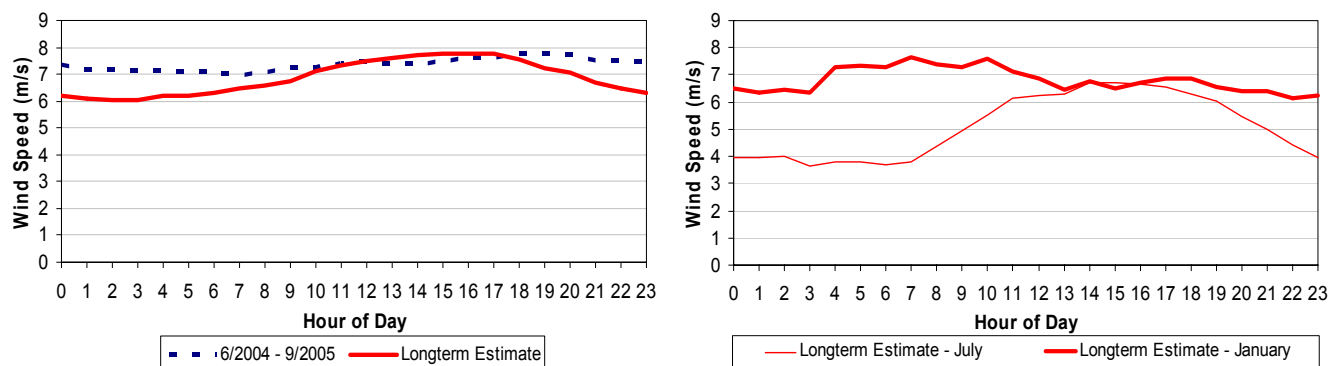
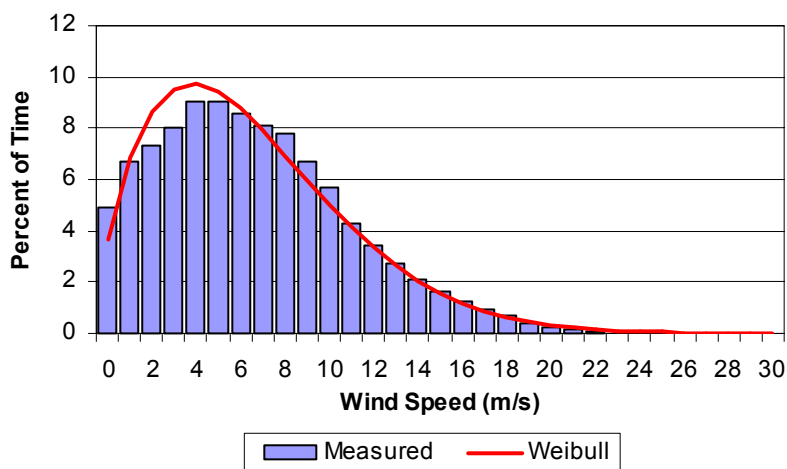


Figure 5. Hourly Average Wind Speeds at Met Tower Site (30m Height)

A common method of displaying a year of wind data is a wind frequency distribution, which shows the percent of the year that each wind speed occurs. Figure 6 shows the measured wind frequency distribution as well as the best matched Weibull distribution ($c = 7.88$, $k = 1.62$).



Bin m/s	Measured Hours	Bin m/s	Measured Hours
0	430	15	143
1	589	16	109
2	644	17	83
3	700	18	64
4	789	19	34
5	794	20	23
6	749	21	15
7	709	22	9
8	683	23	3
9	585	24	2
10	500	25	2
11	376	26	1
12	303	27	1
13	237	28	0
14	184	29	0
Total:		8,760	

Figure 6. Wind Speed Frequency Distribution of Measured Met Tower Data

The cut-in wind speed of many wind turbines is 4 m/s and the cut-out wind speed is around 25 m/s. The frequency distribution shows that a large percentage of the wind in Toksook is within this operational zone.

Table 6 shows the annual wind rose at the Toksook Bay met tower site versus the Mekoryuk Airport. The correlation coefficient of the directional data between the Mekoryuk and Toksook Bay sites is 0.72. Table 7 shows the monthly wind roses for the year of data measured at the Toksook Bay met tower.

Table 6. Annual Wind Rose for Met Tower Site and Airport Site

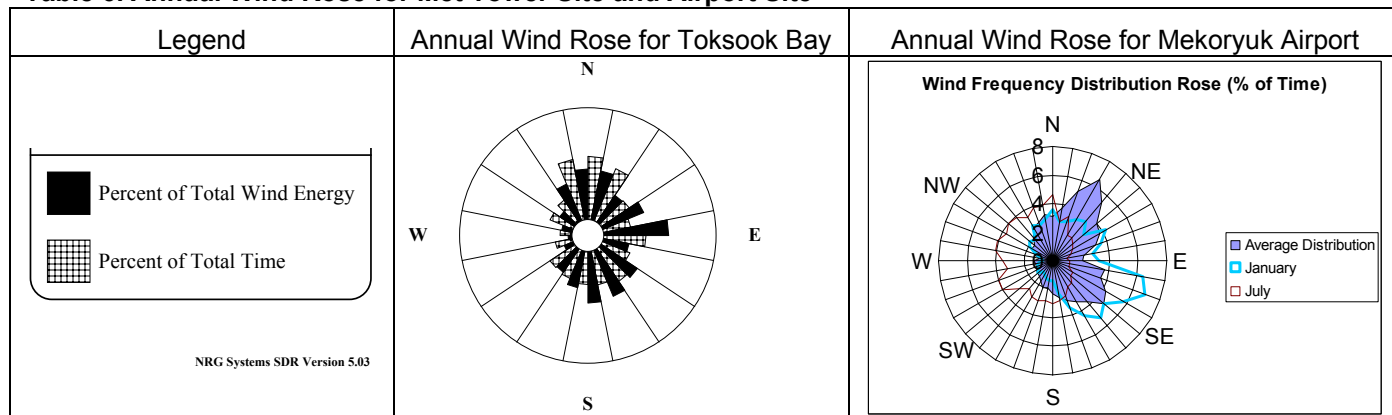


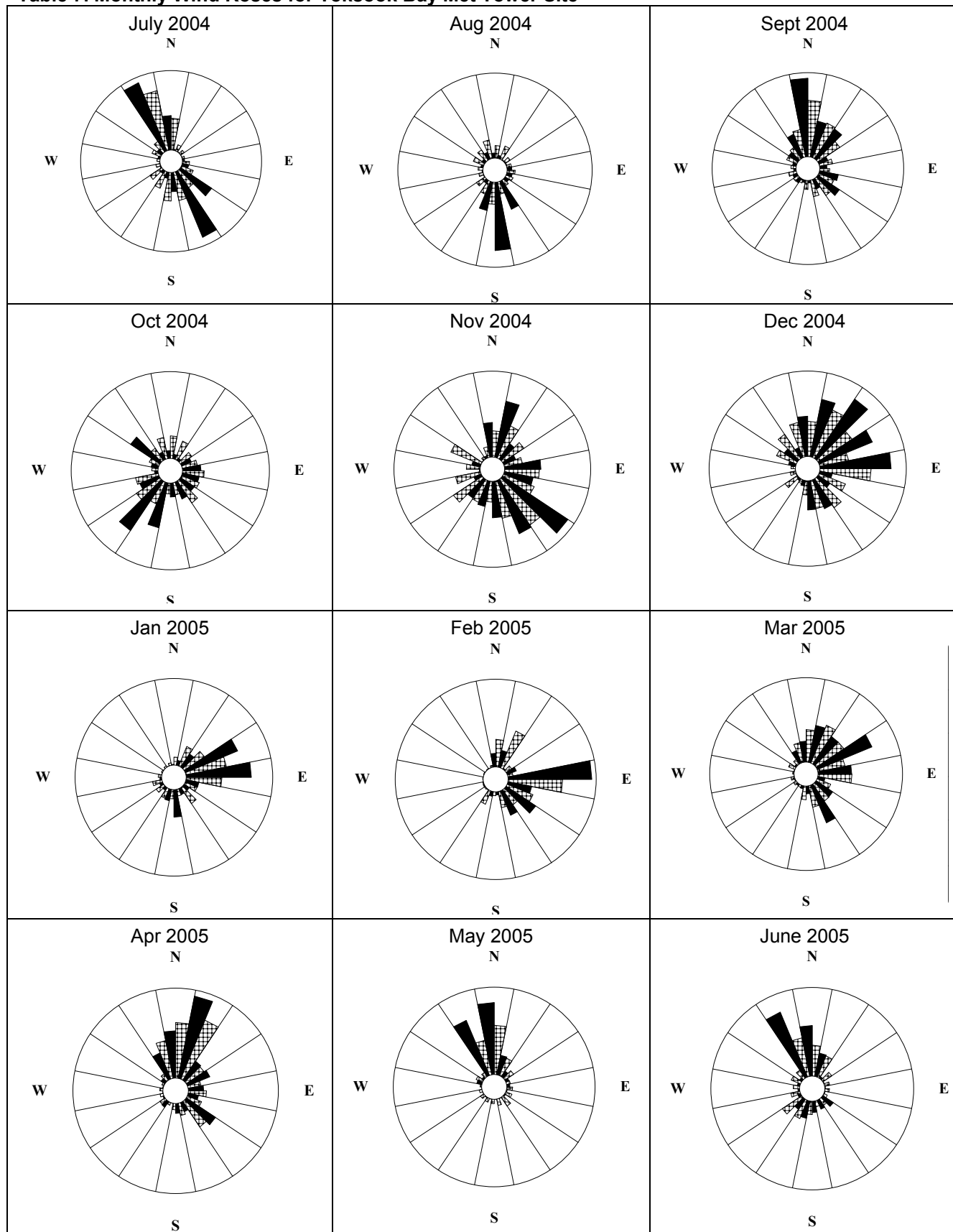
Table 7. Monthly Wind Roses for Toksook Bay Met Tower Site

Table 8 summarizes the monthly turbulence intensity and wind shear at the met tower site. A turbulence intensity of less than 0.10 is considered low and unlikely to contribute to excessive wear of wind turbines. Wind shear was calculated between the 30-meter anemometer and the 20-meter anemometer. Both turbulence intensity and wind shear were only calculated for wind speeds greater than 4 m/s.

Table 8. Monthly Turbulence Intensity and Wind Shear at Met Tower Site – June 2004 to Aug 2005

Month	Turbulence Intensity	30m to 50m Wind Shear
Jan	0.15	0.14
Feb	0.10	0.11
Mar	0.10	0.15
Apr	0.11	0.09
May	0.11	0.08
Jun	0.10	0.11
Jul	0.12	0.05
Aug	0.10	0.13
Sep	0.11	0.15
Oct	0.10	0.17
Nov	0.09	0.20
Dec	0.10	0.14
Annual Avg	0.11	0.14

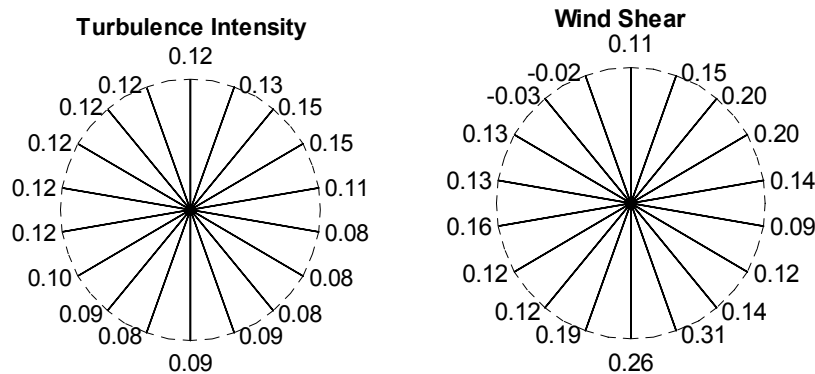


Figure 7. Turbulence Intensity and Wind Shear by Direction, June 2004 - Aug 2005

The air temperature can affect wind power production in two primary ways: 1) colder temperatures lead to higher air densities and therefore more power production, and 2) some wind turbines shut down in very cold situations (usually around -25°C). The monthly average temperatures measured at the met tower are shown in Figure 8. The temperature never dropped below -25°C and was below -20°C for about 150 hours of the year.

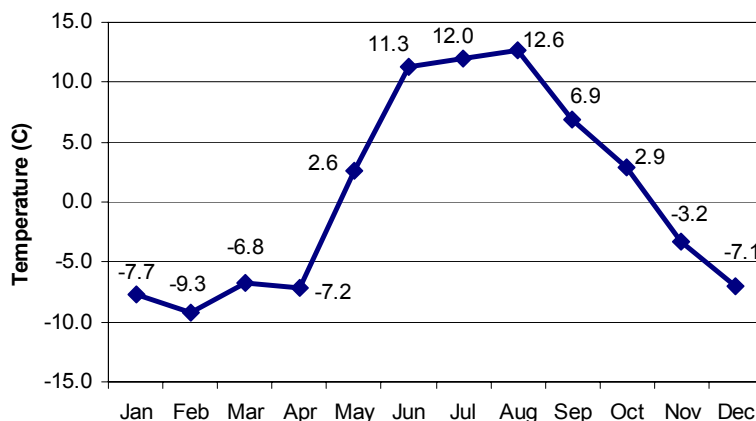


Figure 8. Monthly Average Temperatures at Toksook Bay Met Tower Site

POTENTIAL POWER PRODUCTION FROM WIND TURBINES IN TOKSOOK BAY

Table 9 lists a number of parameters used to characterize the power production potential of a particular site.

Table 9. Summary of Power Production Potential of Met Tower Site

Average Wind Power Density (30m)	518 W/m ²
Wind Power Class	6
Rating	Outstanding

Various wind turbines, listed in Table 12, were used to calculate energy production at the met tower site based on the long-term wind resource data set. Results are shown in Table 10. Although different wind turbines are offered with different tower heights, to be consistent it is assumed that any wind turbine rated at 100 kW or less would be mounted on a 30-meter tall tower, while anything larger would be mounted on a 50-meter tower. The wind resource was adjusted to these heights based on the measured wind shear at the site.

Table 10. Gross Annual Energy Production from Different Wind Turbines at Met Tower Site

Month	Proven 2.5kW	Proven 6kW	Bergey 10 kW	FL30	Entegritty	FL100	NW100	FL250	V27	V47
Jan	716	1,814	1,959	9,065	14,937	29,251	23,807	67,748	61,260	204,550
Feb	714	1,827	2,005	9,131	14,852	29,233	23,918	65,900	60,080	202,436
Mar	990	2,474	2,663	12,350	21,377	41,206	33,671	93,442	85,219	278,858
Apr	835	2,138	2,329	10,618	17,875	34,643	28,582	75,591	69,936	235,723
May	471	1,249	1,329	6,228	9,063	18,244	14,859	40,806	37,271	133,511
Jun	351	933	975	4,514	6,424	13,190	10,746	30,535	27,874	97,501
Jul	369	975	980	4,700	6,303	13,144	10,535	29,339	26,376	94,347
Aug	426	1,115	1,172	5,489	8,104	16,360	13,266	38,609	35,150	122,059
Sep	527	1,396	1,490	6,943	10,308	20,652	16,885	49,813	45,611	159,515
Oct	1,020	2,554	2,666	12,770	22,139	42,236	34,503	98,340	89,047	292,766
Nov	925	2,297	2,337	11,431	19,973	37,927	30,840	88,086	79,760	260,861
Dec	846	2,124	2,169	10,710	17,916	34,377	27,813	79,753	72,035	241,488
Annual	8,190	20,895	22,072	103,948	169,271	330,464	269,426	757,962	689,619	2,323,615
Annual kWh/m ²	853	878	573	782	956	950	949	1,108	1,204	1,339

Table 10 also lists the annual energy production per square meter of swept area (kWh/m²). This allows one to directly compare the efficiency of one wind turbine against another, as shown in Figure 9.

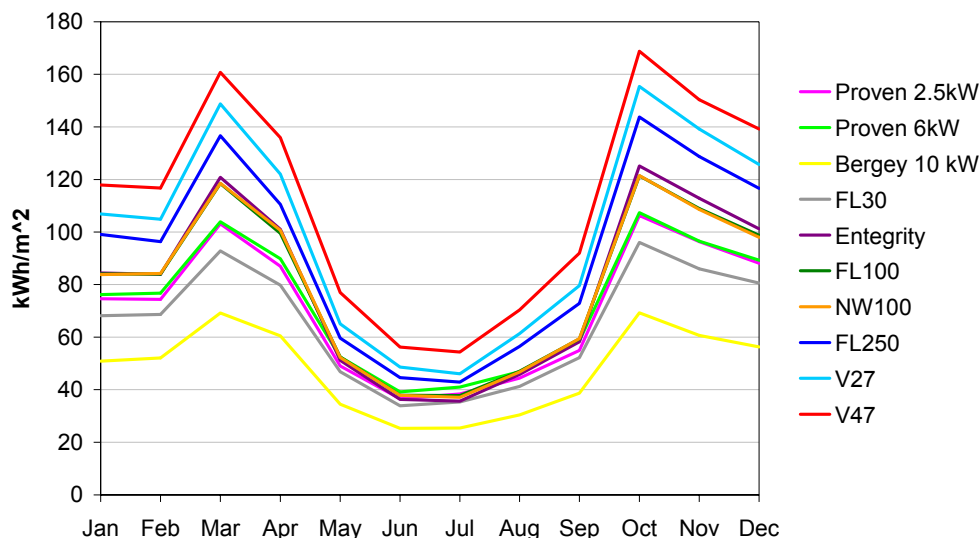


Figure 9. Comparison of Power Production per Square Meter of Swept Area from Various Wind Turbines

Table 11 summarizes the gross capacity factor of the wind turbines per month. Gross capacity factor is the amount of energy produced based on the given wind resource divided by the maximum amount of energy that could be produced if the wind turbine were to operate at rated power during that entire period. The gross capacity factor could be further reduced by up to 10% to account for transformer/line losses, turbine downtime, soiling of the blades, icing of the blades, yaw losses, and extreme weather conditions.

Table 11. Gross Capacity Factor of Different Wind Turbines at Met Tower Site


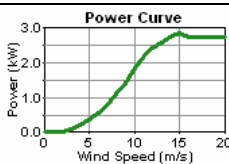

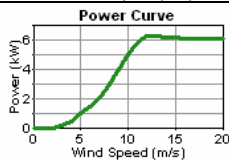

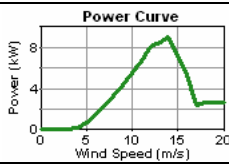

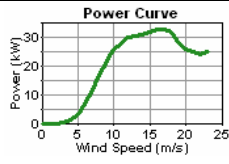

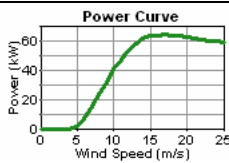

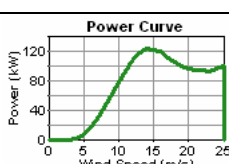

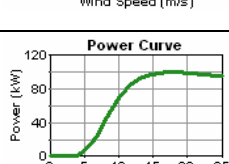

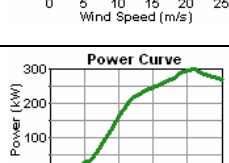

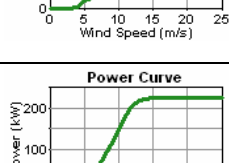

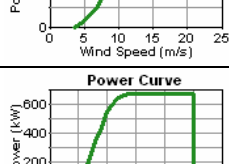
Month	Proven 2.5kW	Proven 6kW	Bergey 10 kW	FL30	Entegritty	FL100	NW100	FL250	V27	V47
Jan	39%	41%	26%	41%	30%	39%	32%	36%	37%	42%
Feb	42%	45%	30%	45%	33%	44%	36%	39%	40%	46%
Mar	53%	55%	36%	55%	44%	55%	45%	50%	51%	57%
Apr	46%	49%	32%	49%	38%	48%	40%	42%	43%	50%
May	25%	28%	18%	28%	18%	25%	20%	22%	22%	27%
Jun	20%	22%	14%	21%	14%	18%	15%	17%	17%	21%
Jul	20%	22%	13%	21%	13%	18%	14%	16%	16%	19%
Aug	23%	25%	16%	25%	17%	22%	18%	21%	21%	25%
Sep	29%	32%	21%	32%	22%	29%	23%	28%	28%	34%
Oct	55%	57%	36%	57%	45%	57%	46%	53%	53%	60%
Nov	51%	53%	32%	53%	42%	53%	43%	49%	49%	55%
Dec	45%	48%	29%	48%	36%	46%	37%	43%	43%	49%
Annual	37%	40%	25%	40%	29%	38%	31%	35%	35%	40%

CONCLUSION

This report provides a summary of wind resource data collected from June 2004 through August 2005 in Toksook Bay, Alaska. The data was compared to long-term trends in the area. Based on correlations with the Mekoryuk weather station, estimates were made to create a long-term dataset for the Toksook Bay met tower site. This information was used to make predictions as to the potential energy production from wind turbines at the site.

It is estimated that the long-term annual average wind speed at the site is 6.9 m/s at a height of 30 meters above ground level. Taking the local air density into account, the average wind power density for the site is 518 w/m². This information means that Toksook Bay has a Class 6 wind resource, which is outstanding for wind power development.

Table 12. Specifications of Wind Turbines Used in Power Production Analysis

Proven 2.5 kW http://www.provenenergy.com			Tower Height: 30 meters Swept Area: 9.6 m ² Turbine Weight: 190 kg
Proven 6 kW http://www.provenenergy.com			Tower Height: 30 meters Swept Area: 23.8 m ² Turbine Weight: 500 kg
Bergey 10 kW www.bergey.com			Tower Height: 30 meters Swept Area: 38.5 m ² Weight: not available
Fuhrlander FL30 30 kW www.lorax-energy.com			Tower Height: 30 meters Swept Area: 133 m ² Weight (nacelle & rotor): 410 kg
Entegrety 66 kW www.entegretywind.com			Tower Height: 30 meters Swept Area: 177 m ² Weight (drivetrain & rotor): 2,420 kg
Fuhrlander FL100 100 kW www.lorax-energy.com			Tower Height: 30 meters Swept Area: 348 m ² Weight (nacelle & rotor): 2,380 kg
Northern Power NW100/19 100 kW www.northernpower.com			Tower Height: 30 meters Swept Area: 284 m ² Weight (nacelle & rotor): 7,086 kg
Fuhrlander FL250 250 kW www.lorax-energy.com			Tower Height: 50 meters Swept Area: 684 m ² Weight (nacelle & rotor): 4,050 kg
Vestas V27 225 kW (refurbished, various suppliers)			Tower Height: 50 meters Swept Area: 573 m ² Weight: not available
Vestas V47 660 kW www.vestas.com			Tower Height: 50 meters Swept Area: 1,735 m ² Weight: not available

